SO_2 NAAQS Compliance Modeling Report for the Rhinelander Mill

Ahlstrom-Munksjö
Rhinelander, WI

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Quality information

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1. Introduction

1.1 Background

In 2010, the United States Environmental Protection Agency (U.S. EPA) promulgated a more stringent National Ambient Air Quality Standard (NAAQS) for SO_2 at 75 ppb[1] and established a 1-hour averaging time for the standard. The ambient air monitor for the City of Rhinelander, Wisconsin (Oneida County) at the Water Tower location indicated SO_2 concentrations higher than this new standard. As a result, the area was designated in 2013 by the U.S. EPA as an SO_2 non-attainment area.[2]

An analysis of local emission sources and air quality modeling by the Wisconsin Department of Natural Resources (WDNR) indicated that the paper mill in Rhinelander currently operated by Ahlstrom-Munksjö was- the primary contributor at this monitor, despite modeling using the U.S. EPA's preferred stationary source model (AERMOD) demonstrating compliance by that mill with the 1-hour standard. In 2011, AECOM and CPP were retained by the mill to determine and help mitigate the cause of the monitored NAAQS violations. CPP confirmed through a comprehensive wind tunnel study that the highest concentrations are expected at the Water Tower location, and noted that the presence of a tall mill structure (Boiler Building No. 7) upwind of the principal coal-fired cyclone boiler (exhausting to stack S09) was a complicating factor for impacts at this site (see Figure 1-1). The boiler building was oriented with winds from the south so that the approaching flow would first encounter a building corner, thus leading to a corner vortex aerodynamic effect that is not currently able to be simulated in AERMOD. This effect leads to a uniquely vigorous downdraft in the vicinity of the stack that results in lower plume rise and increased ground-level concentrations than those simulated in AERMOD, which currently does not simulate corner vortex effects of this type.

CPP's wind tunnel was used to determine[3] a site-specific good engineering practice ("GEP") stack height for S09 that would avoid building downwash effects noted above. The result of this analysis was that a S09 stack height of 90 m (increased from the then-current 63 m) would reduce the added downwash concentrations below 40% of the concentrations present in the absence of the building. The mill then increased the S09 stack height to 90 m in 2016 to mitigate the downwash effects that were causing the high monitored concentrations. A time series of the 99th percentile peak daily 1-hour maximum ("design") concentrations at the Water Tower monitor for 2010-2019 shown in Figure 1-2 indicates that the S09 stack height increase was quite effective at reducing the SO_2 concentrations at the monitor by a factor of about 4, even with some SO_2 emission reductions for S09 (on the order of 25-30%) due to lower sulfur coal and dry sorbent injection controls.

1.2 Further Review of Creditable Stack Height by EPA

After further review of the CPP wind tunnel study (which used the old SO_2 permit limit of 3.5 lb/MMBtu, although the 40% downwash effect is driven by the corner vortex and exists regardless of the limit applied), the U.S. EPA requested in 2019 that before the agency approves a site-specific GEP stack height for the facility, the facility and the WDNR consider two options. These options are: (1) modeling the facility at the formula ("creditable") stack height; or (2) provide additional information that use of an emission rate that is prescribed by the New Source Performance Standards (NSPS) applicable to the industrial source category is infeasible, and that the facility's emission rate constitutes Best Available Retrofit Technology ("BART").

This report addresses the first option proposed by the U.S. EPA, specifically, modeling the facility at a GEP formula height with the wind tunnel site-specific adjustments to the building downwash effect (achieved with use of hourly-varying emission rates). Due to the fact that the mill's SO_2 emissions are below 5,000 tons

[1] The form of the 1-hour SO_2 NAAQS is the 99th percentile peak daily 1-hour maximum, averaged over 3 years. For a given year, the form of the standard involves the 4th highest day.
[2] 78 Fed. Reg. 47,191, August 5, 2013.
[3] CPP, Inc. 2014. *Fluid Modeling Good Engineering Practice Stack Height Determination for the Rhinelander Mill Stack S09*. CPP Project 7835.

per year, modeling the stack at the formula GEP height is creditable. The analysis presented in this report conducts a load analysis to justify the use of full load as the most controlling case and determines a NAAQS-compliant mass-based (lb/hr) SO_2 emission rate for that worst-case load.

In July 2020, Ahlstrom-Munksjö and AECOM issued a modeling report that documented a GEP formula height of 80 m for the cyclone boiler stack (Stack 09). EPA commented that this calculation included the S10 stack in the building width calculations. However, since the stack is a rounded structure, EPA indicated that it should not be factored into the building width calculation without further wind tunnel studies to evaluate the effect of the S10 stack on the building wake. EPA indicated that the GEP height without considering the S10 stack is 75 m. Although not necessarily agreeing with EPA that the S10 stack has no effect on the building downwash, Ahlstrom-Munksjö has decided not to conduct further wind tunnel analyses at this time, so this report will use the EPA-determined GEP height of 75 m as a conservatively low value for the GEP formula height affecting the cyclone boiler stack. Therefore, the modeled concentrations are likely to overstate the air quality impacts because there are expected to be some downwash effects from the S10 stack that are being ignored in the modeling.

1.3 Document Organization

Section 2 reviews the GEP height for Stack 09 to document that without consideration of the S10 stack, a formula height of 75 m (rounded to the nearest whole meter) is the resulting value. Adjustments to the AERMOD model to enable it to account for the corner vortex effect based upon CPP wind tunnel results are discussed in Section 3. Section 4 provides a description of the AERMOD modeling approach. Section 5 presents a review of three different load cases to demonstrate that a high load case is the most constraining case for a lb/hr SO_2 emission limit. Based upon this determination, Section 6 provides the modeling result for the complying 1-hour lb/hr emission limit. Ahlstrom-Munksjö is requesting a daily average emission limit; Section 6 also discusses the equivalent daily SO_2 emission rate based upon EPA guidance.

Appendix A provides a report by Dr. Ron Petersen, who supervised the wind tunnel modeling for this mill, that establishes the appropriate model adjustments for the building corner vortex effects. Appendix B provides relevant portions of stack test results for stack S09 to support the exhaust characteristics used for the worst-case load analysis.

Figure 1-1: View of Boiler Building, S09 Stack, and Water Tower in Rhinelander, WI

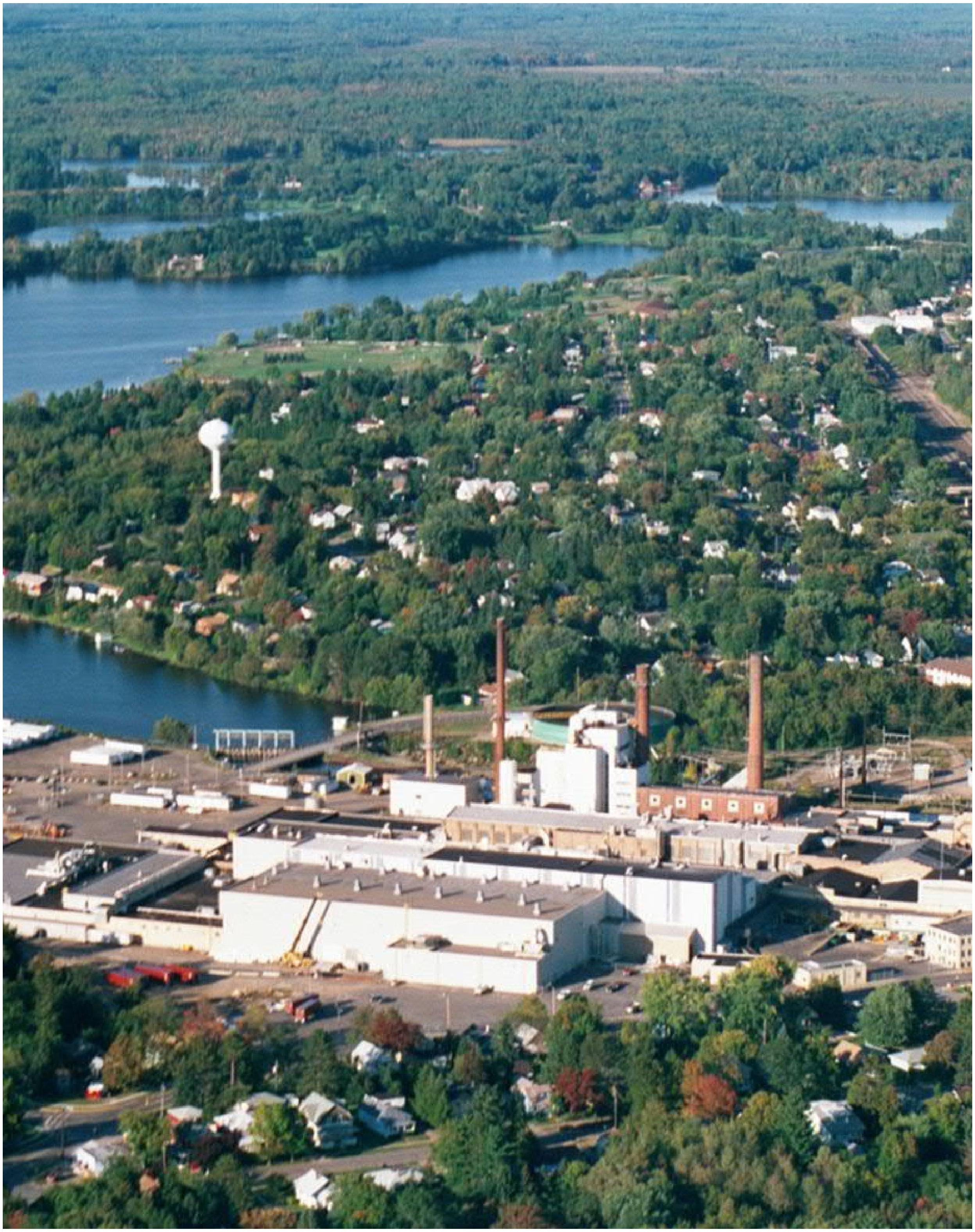


Figure 1-2: Time Series of SO_2 1-Hour Design Concentrations at the Water Tower Monitor

2. Formula GEP Height For the Cyclone Stack S09

In July 2020, Ahlstrom-Munksjö and AECOM issued a modeling report that documented a GEP formula height of 80 m for the cyclone boiler stack (Stack 09). EPA commented that this calculation included the S10 stack in the building width calculation. However, since the S10 stack is a rounded structure, EPA indicated that this stack should not be factored into the building width calculation without further wind tunnel studies to evaluate the effect of the S10 stack on the building wake. Ahlstrom-Munksjö has decided not to conduct further wind tunnel analyses at this time, so this report will use the EPA-determined GEP height of 75 m for the cyclone boiler stack.

The formula GEP stack height is given by equation (1), taken from U.S. EPA's 1985 GEP guidance document.

$$Hg = H + 1.5 * L \qquad (1)$$

where Hg is the good engineering practice stack height measured from the ground-level elevation at the base of the stack, H is the height of the nearby structure measured from the ground-level elevation at the base of the stack, and L is the lesser dimension, either height or projected width of the nearby structure. In the case of a tall structure such as Boiler Building No. 7, L is the projected width.

Figure 2-1 is an aerial photo that shows the relationship between Boiler Building No. 7 and Stack 09. Figure 2-2 shows more detail of the Building No. 7 roof. The building width (L in Eqn. 1) is determined from the diagonal from survey points 108 and 119 from Figure 2-2; that dimension is 80.8 feet, or 24.63 m.

H is determined by taking the difference in survey points 119 and 128 in the mill survey based upon a mill survey drawing of the building, as provided in Table 2-1. Point 119 is the top elevation of the main roof of boiler building No. 7 and point 128 is the base elevation of Stack 09. The elevations are given in Table 2-1 as 1685.1 ft and 1560.4 ft, respectively. The difference between these two values results in a value of 124.7 ft, or 38.01 m for H.

The resulting GEP formula height is 74.96 m, rounded to 75 m for use in the modeling. This calculated GEP formula height is conservatively low because it ignores the effects of Stack S10 as well as some miscellaneous rooftop structures. Therefore, the modeling using this formula height will tend to overstate the modeled concentration impacts.

Figure 2-1: Aerial Image of Boiler Building No. 7 and Stacks 9 and 10 Prior to Stack Change

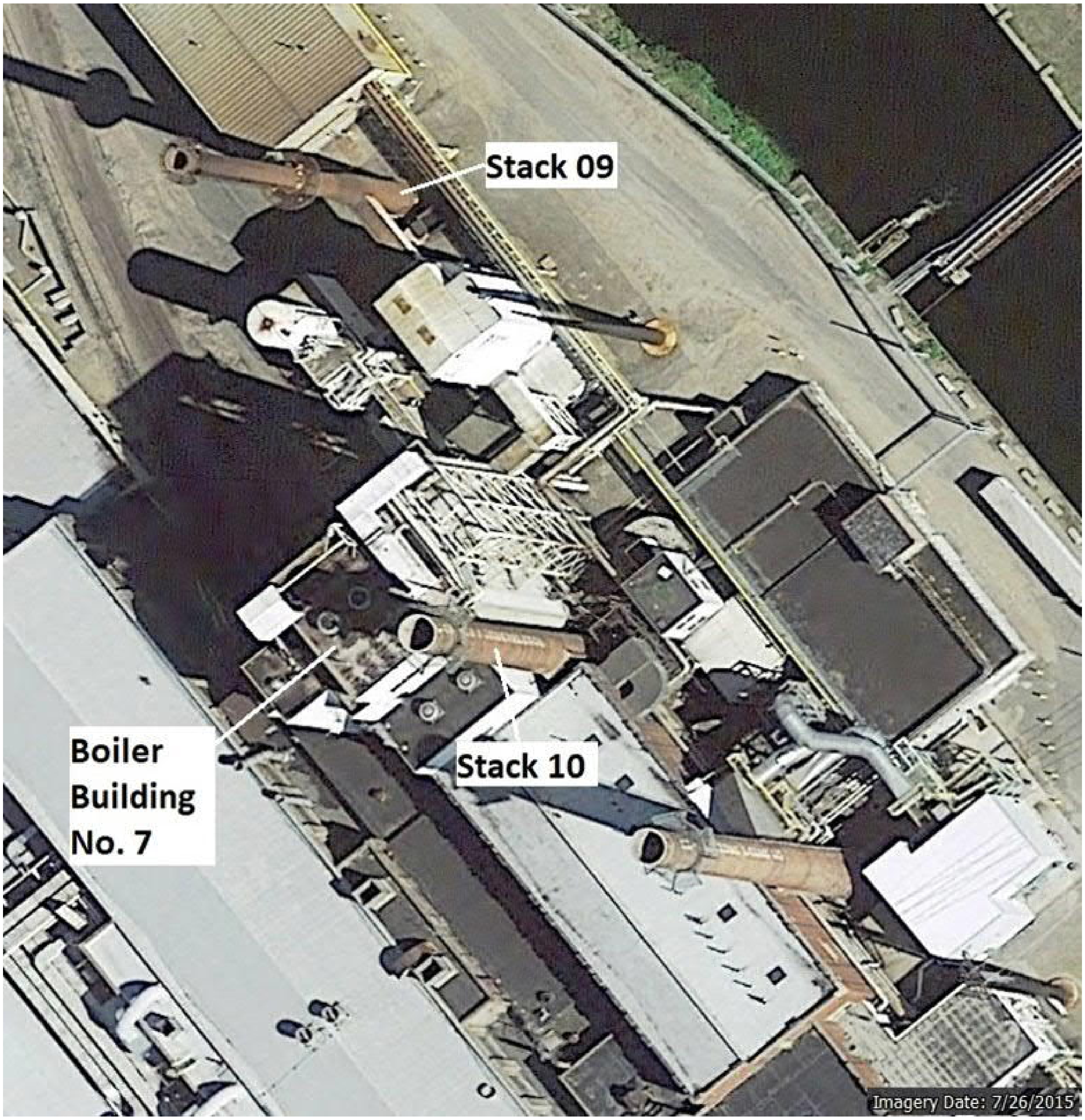


Figure 2-2: Depiction of Boiler Building No. 7 Roof

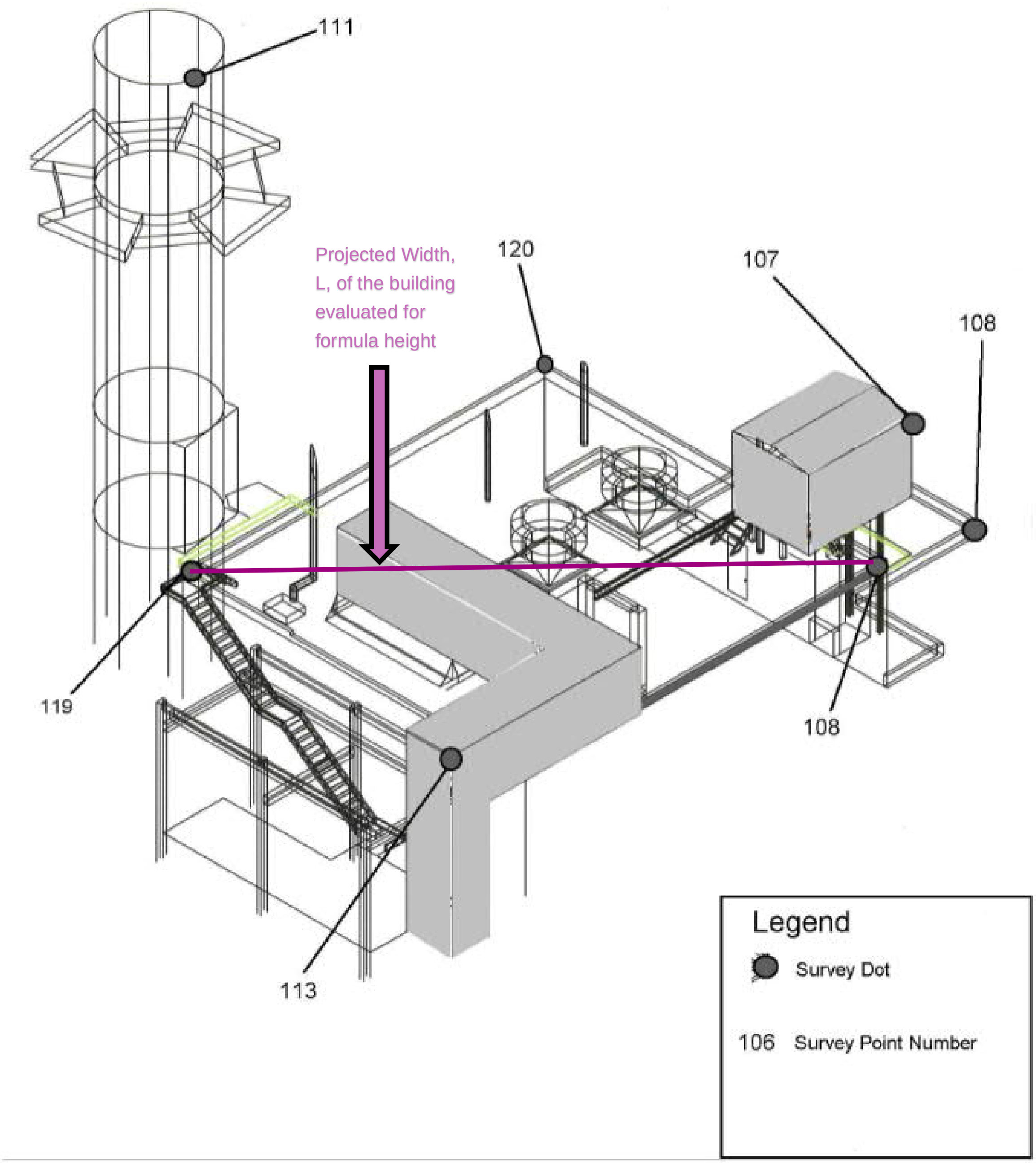


Table 2-1: Rhinelander Mill Survey Key

Survey Point Number	Elevation (ft)	Location Note
101	1624.3	Top of the Building Corner
102	1624.1	Top of the Building Corner
103	1608.9	Top of the Building Corner
104	1608.9	Top of the Building Corner
106	1665.7	Top of the Building Corner
107	1692.1	Top of the Building Corner
108	1681.1	Top of the Building Corner
109	1680.2	Top of Stack
110	1770.9	Top of Stack
111	1756.0	Top of Stack
112	1739.7	Top of Stack
113	1690.4	Top of the Building
114	1597.8	Top of the Building
115	1596.3	Top of the Building
116	1562.7	Building Base
117	1563.1	Building Base
118	1620.0	Top of the Building
119	1685.1	Top of the Building
120	1681.0	Top of the Building
121	1627.2	Top of the Building
122	1555.5	Stack Base
123	1554.2	Building Base
124	1617.7	Top of the Building
125	1617.9	Top of the Building
126	1557.0	Stack Base
127	1563.0	No. 8 Boiler House Floor
128	1560.4	Stack Base
130	1556.6	Building Base
131	1556.8	Building Base
132	1585.3	Base of Building 21, Top of Building 79
133	1585.9	Top of the Building
134	1569.7	Building Base
135	1585.9	Top of the Building
136	1565.3	Building Base
137	1617.7	Top of the Building
138	1583.9	Top of Building 79, Midpoint of Building 118
139	1617.7	Top of the Building
140	1563.5	Building Base
141	1559.6	Building Base
142	1628.7	Top of the Building
143	1586.7	Top of the Building
144	1586.8	Top of the Building
145	1557.0	Building Base
146	1608.5	Top of the Building
147	1608.5	Top of the Building
148	1588.2	Top of the Building
149	1547.5	Top of the Building
150	1546.0	Building Base
151	1626.6	Top of the Building
152	1609.4	Top of the Building
153	1561.0	Building Base

3. Modeling Adjustments to Account for Corner Vortex Effects

In coordination with the WDNR and the U.S. EPA, AECOM conducted AERMOD modeling of the 90-m S09 stack emissions in 2015 to determine whether the SO_2 NAAQS would be attained in all locations in the Rhinelander area with the benefit of the site-specific GEP stack. Due to the inability of AERMOD to simulate the effects of the corner vortex, the agencies agreed that AERMOD concentrations should be adjusted using relationships from the CPP wind tunnel investigations to allow AERMOD to properly account for building downwash effects for this specific modeling application.

Appendix A provides documentation of the derivation of the relationship updated for a 75-m formula GEP stack, and a summary of the formulation is provided in this section.

The adjustments were derived from the results in Table 5 from CPP's 2014 fluid modeling report.[4] That table provides the concentration ratio, R, of maximum concentration with the buildings present, compared to the concentration without the buildings present for various stack heights, operating scenarios and wind speeds. The maximum and minimum operating load scenarios were found to provide very similar R values at the 85-m stack height and maximum load scenario was selected as the critical scenario for documenting the 90-m Good Engineering Practice (GEP) stack height. At the 85-m stack height, R versus wind speed was documented and illustrated that R will tend to decrease as wind speed decreases. At a low wind speed (high plume rise) of about 2.5 m/s, R was found to approach 1.0 as the plume would rise well beyond any building downwash effects.

To correct the AERMOD results for building downwash effects, a relation between R and the 7.93 m airport wind speed for the creditable S09 stack height was needed. Since only one wind speed was evaluated for stack heights of 87.5, 90, and 95 m, but several wind speed cases were evaluated for an 85-m stack, the 85-m stack height test results (taken from Table 5 in the CPP report) were used to develop the needed wind speed-dependent relationship of R vs. wind speed. This relationship has the following characteristics: 1) it approaches 1.0 asymptotically as wind speed decreases to 2.5 m/s and 2) it approaches a constant value at a high wind speed where the plume rise remains relatively constant.

The following Gaussian type equation meets these requirements:

$$R = A\,exp\left[-\frac{\left(\frac{1}{U_{airport}}-\frac{1}{U_{max}}\right)^2}{B^2}\right] + 1.0 \qquad (2)$$

where $U_{airport}$ is the Rhinelander airport wind speed at 7.9 m, U_{max} is the 1% wind speed of 10.8 m/s, and A and B are best-fit constants. Equation 2 has the following characteristics:

- as $U_{airport}$ approaches low wind speeds (i.e., 2.5 m/s), R approaches 1,
- when $U_{airport} = U_{max}$, R = A+1, the maximum value, and
- when $U_{airport} > U_{max}$, R will decrease, and is conservatively set to A+1, the maximum value.

Appendix A provides a discussion for deriving the values of A and B in Equation 1 for a 75-m stack; these values are:

A= 0.825, and

B= 0.174.

[4] Petersen, R.L. and A. Beyer-Lout. *Fluid Modeling Good Engineering Practice Stack Height Determination for the Rhinelander Mill Stack S09*, CPP Report 7835, October 2014.

4. Dispersion Modeling Approach

The suitability of an air quality dispersion model for a particular application is dependent upon several factors. The following selection criteria have been evaluated:

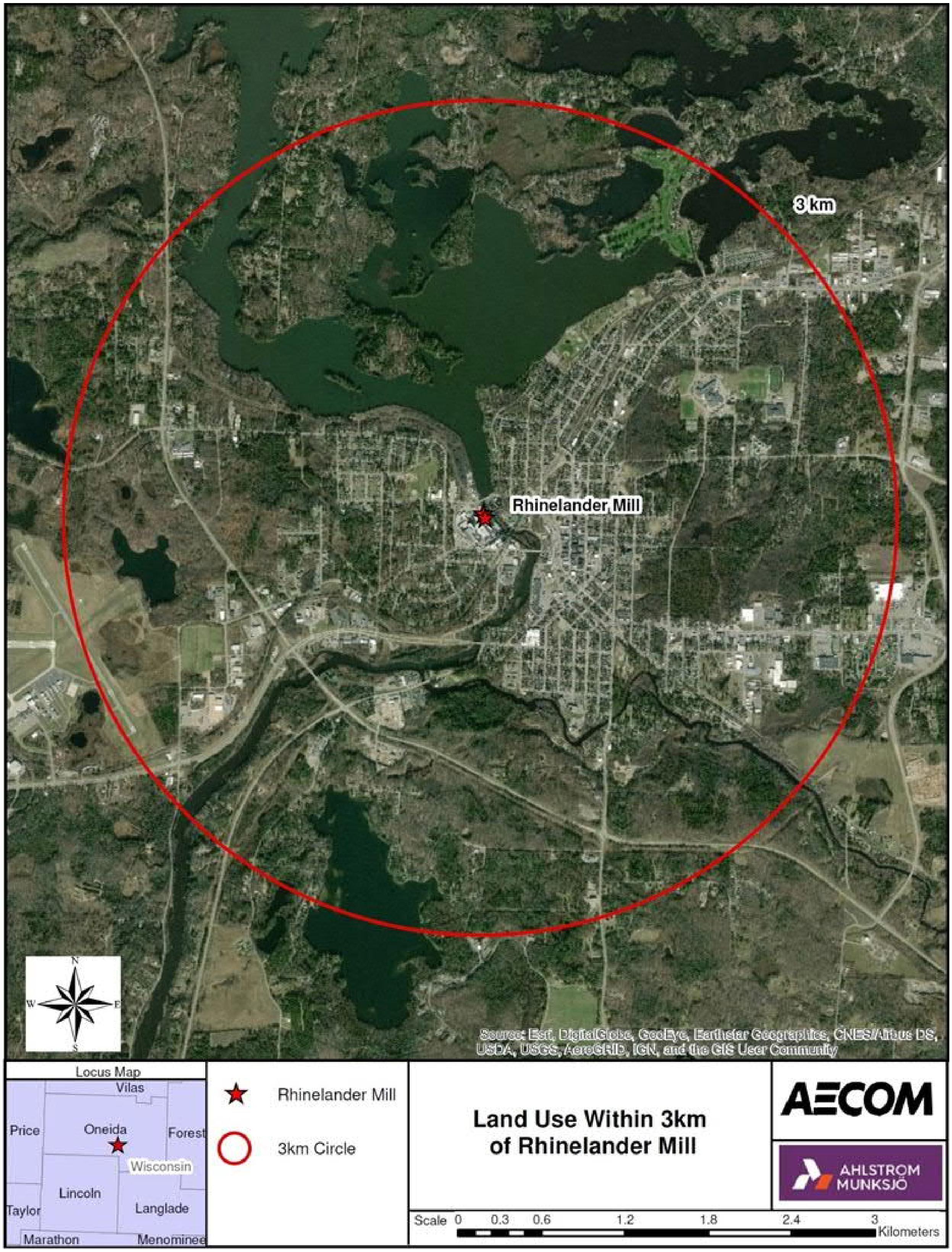
- stack height relative to nearby structures;
- dispersion environment;
- local terrain; and
- representative meteorological data.

The U.S. EPA's Guideline on Air Quality Models (Appendix W to Part 51 of Title 40 of the Code of Federal Regulations) prescribes a set of approved models for regulatory applications for a wide range of source types and dispersion environments. Based on a review of the factors discussed below, the latest version of AERMOD (version 19191) was used to establish SO_2 emission rates in compliance with the SO_2 NAAQS for a range of heat input rates for Stack 09, with adjustments made for the corner vortex building downwash effects.

4.1 Dispersion Environment

The application of AERMOD requires characterization of the local (within 3 kilometers) dispersion environment as either urban or rural, based on a U.S. EPA-recommended procedure that characterizes an area by prevalent land use. This land use approach classifies an area according to 12 land use types. In this scheme, areas of industrial, commercial, and compact residential land use are designated urban. According to the U.S. EPA's modeling guidelines, if more than 50% of an area within a 3-km radius of the facility is classified as rural, then rural dispersion coefficients are to be used in the dispersion modeling analysis. Conversely, if more than 50% of the area is urban, urban dispersion coefficients are used. Consistent with previously accepted modeling analyses conducted for the Rhinelander mill, and as shown in Figure 4-1, the 3-km area surrounding the mill's S09 stack is rural. Therefore, rural dispersion was used in the AERMOD modeling.

Figure 4-1: Land Use Within 3 Km of the Rhinelander Mill Stack S09



4.2 Model Receptor Grid and Terrain

A nested Cartesian (rectangular) receptor grid which was provided by WDNR in 2011 was used with the receptor spacing as described below.

- Boundary – 500 m → 25-meter spacing
- 500 m – 1 km → 50-meter spacing
- 1 km – 3 km → 100-meter spacing
- 3 km – 6 km → 250-meter spacing
- 6 km – 10 km → 500-meter spacing

Figures 4-2 and 4-3 provide the receptor grid as viewed in the near field and far field, respectively.

Receptor height scales at each receptor location were developed by AERMAP (version 18081), the terrain preprocessor for AERMOD, which requires processing of terrain data files. Terrain elevations from USGS National Elevation Dataset (NED) were used to develop the receptor terrain elevations required by AERMOD.

4.3 Meteorological Data Processing

Five full years (2011-2015) of hourly surface observations and one-minute wind speed and direction data from nearby Rhinelander-Oneida County Airport in Rhinelander, Wisconsin were used for the meteorological data processing. These data were used in conjunction with the twice-daily soundings upper air data from Green Bay, Wisconsin in AERMET (version 16216), the meteorological preprocessor for AERMOD, which is consistent with guidance stated in 9.3.1.2 of 40 CFR Part 51, Appendix W (U.S. EPA modeling guidelines). The meteorological data files were processed by WDNR in 2017. At that time, AERMET version 16216 was the current version of the executable. WDNR has not yet processed the meteorological data with the current version of the executable, version 19191, or updated the years being processed. However, we expect insignificant changes between the two versions of AERMET, and WDNR will accept the meteorological files that they provided. The meteorological data was processed using the U.S. EPA-approved Adjusted U* option. AERMINUTE version 15272 was used to process the one-minute data. Figure 4-4 shows the meteorological stations with respect to the Rhinelander Mill.

4.4 Stack S09 Emission Rates for Downwash Effects

Section 5 discusses a load analysis to determine the worst-case load condition. For that load case, a NAAQS-compliant lb/hr SO_2 emission rate was determined, as documented in Section 6. To accommodate the wind-tunnel derived downwash effects, the hourly S09 stack emission rate for input to AERMOD was adjusted by multiplying the NAAQS-compliant emission rate by R, determined from Equation 2 in Section 3 as a function of the hourly airport wind speed. For this modeling, the AERMOD building downwash algorithm was not triggered in AERMOD (no building data was provided) because the downwash effects were simulated with the wind tunnel-derived building effects that modified the hourly emission rate.

Figure 4-2: Far-Field Receptor Grid

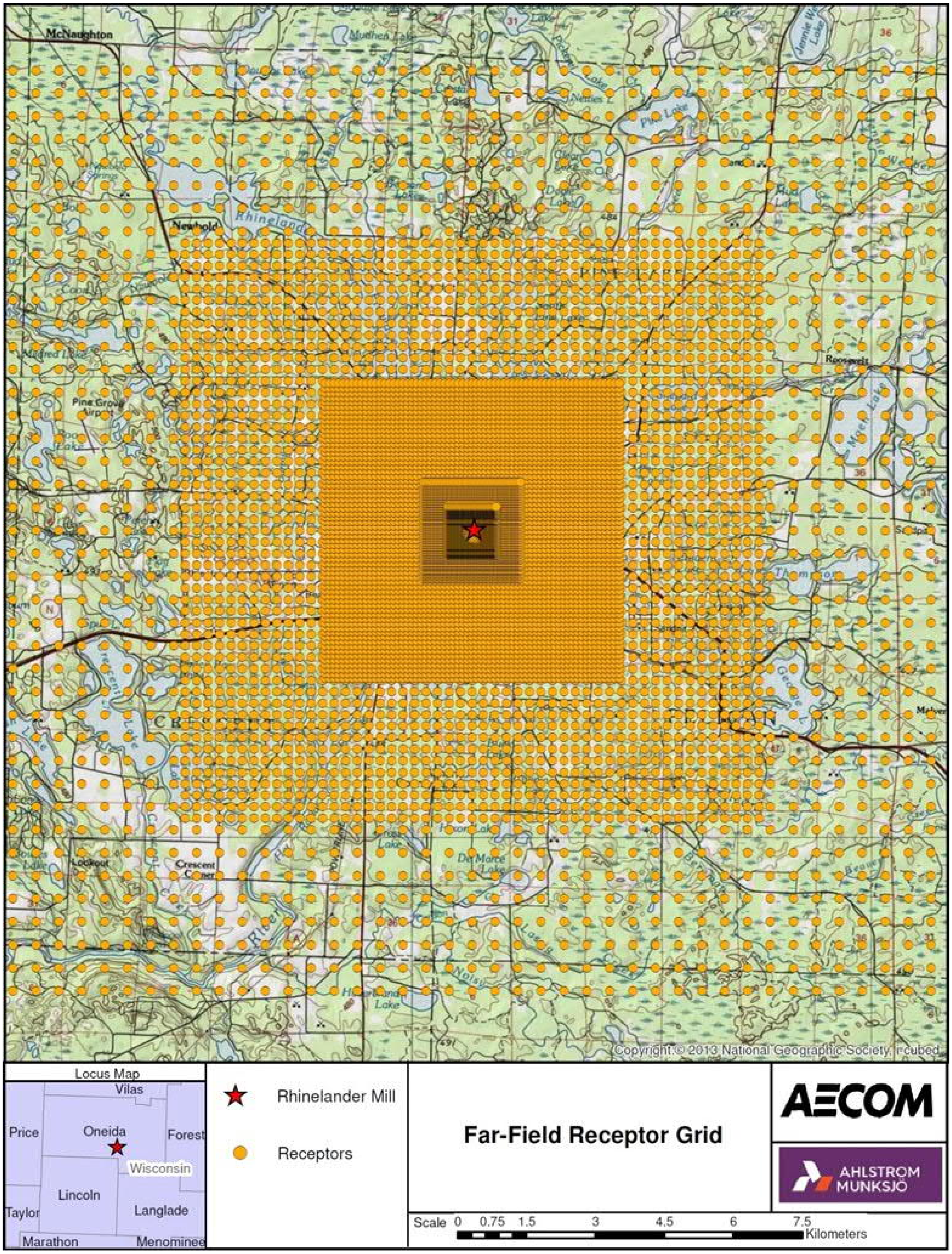


Figure 4-3: Near-Field Receptor Grid

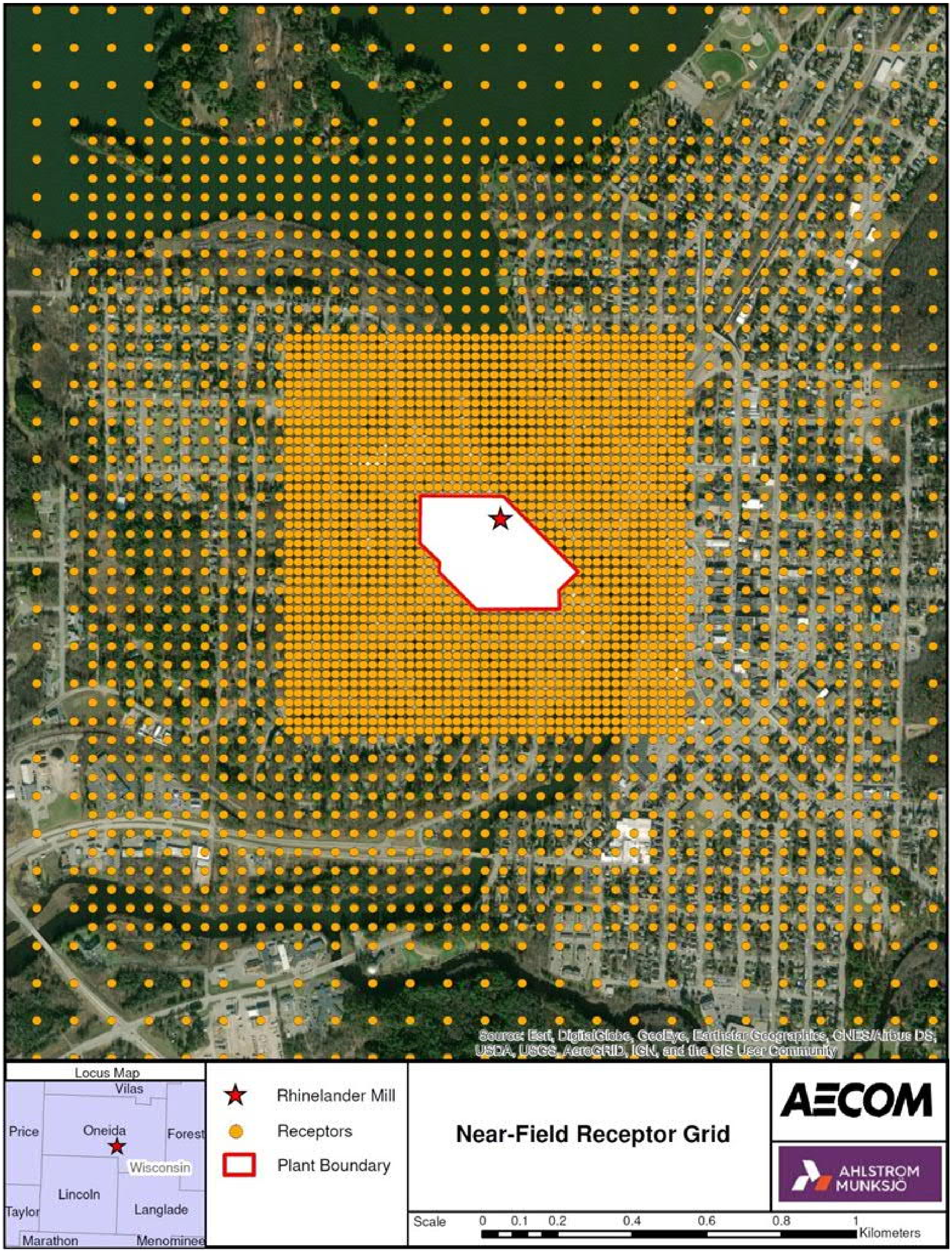
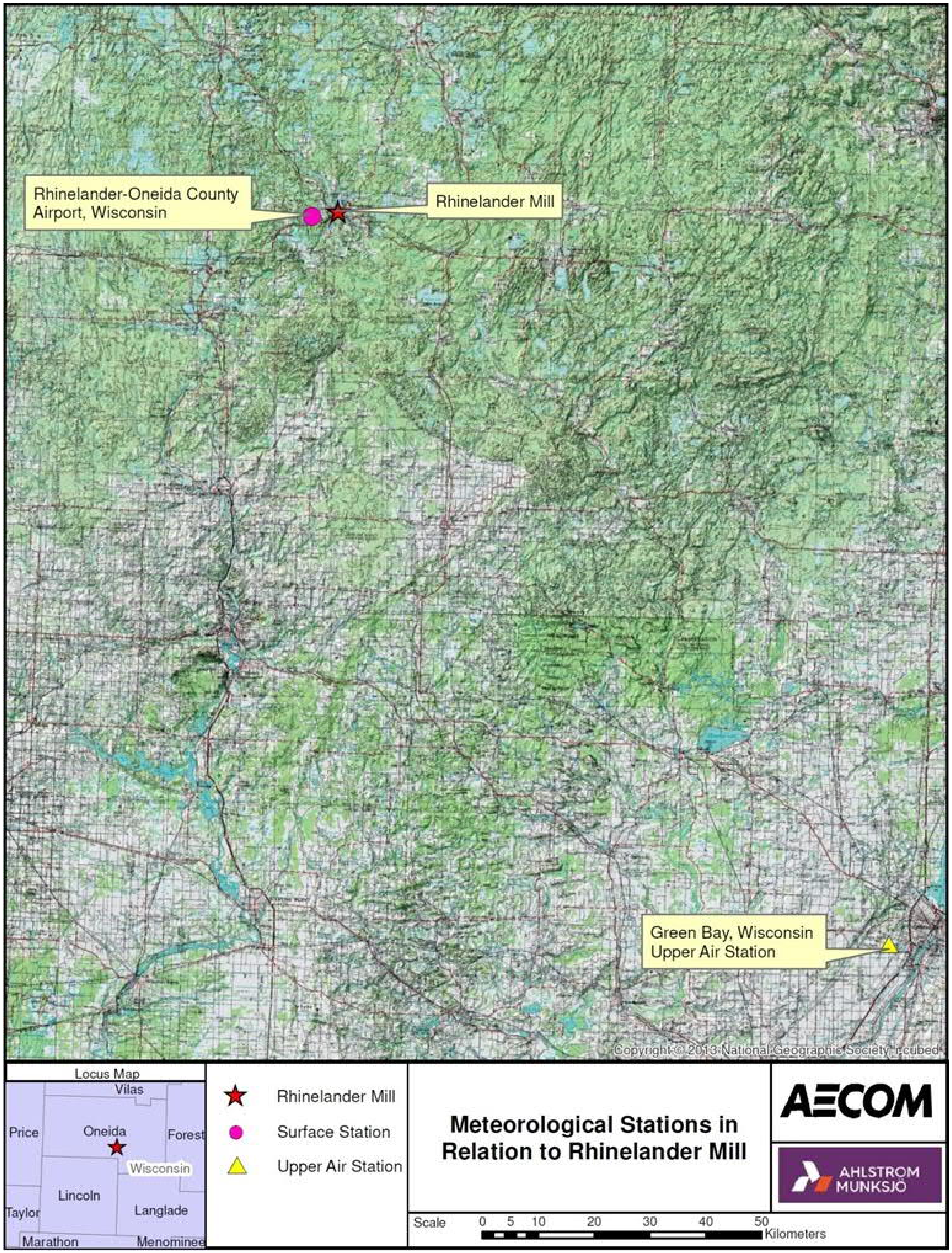


Figure 4-4: Locations of Meteorological Stations



4.5 Background Sources and Monitored Data

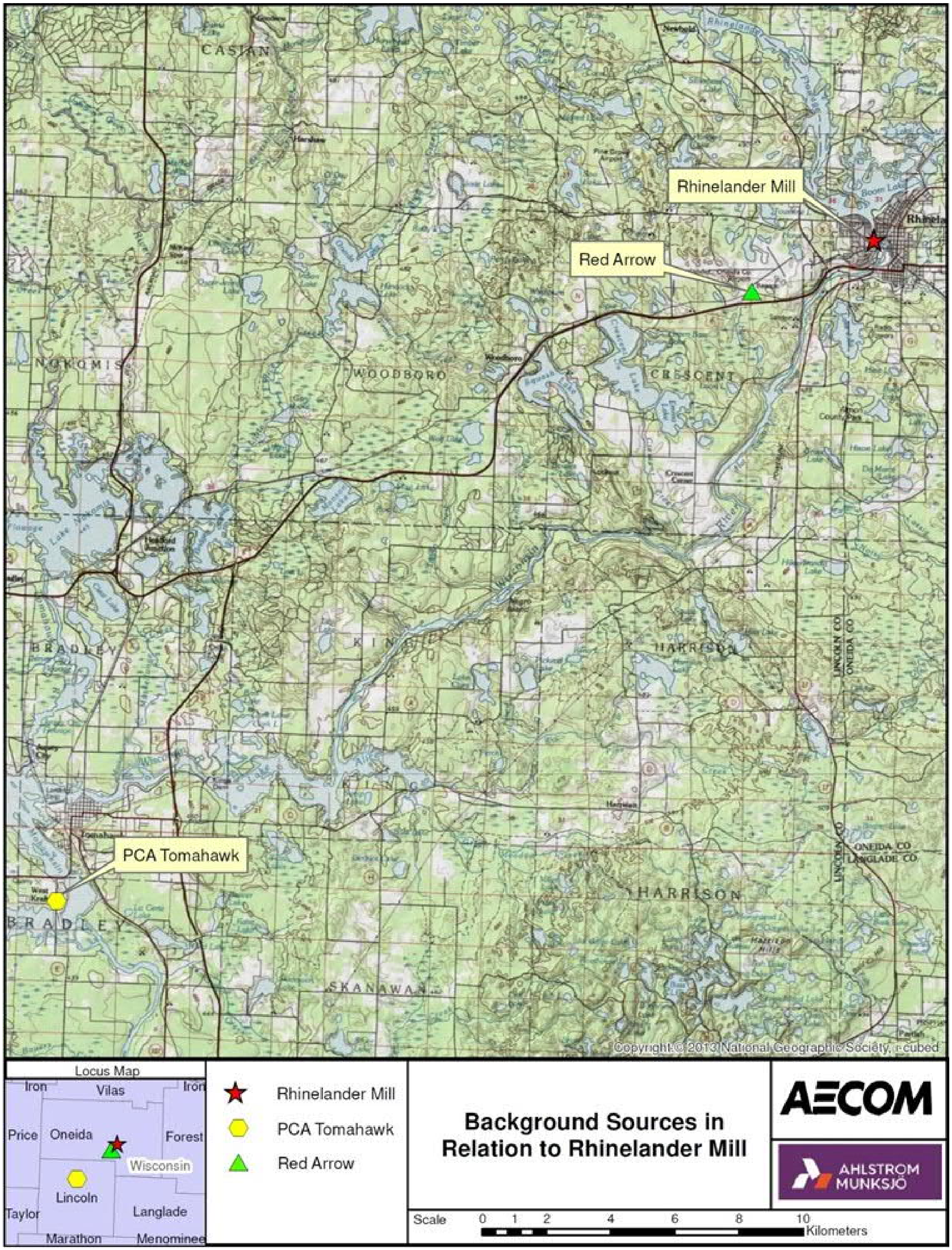
Previous modeling of the Rhinelander Mill included two nearby facilities within 50 km of the Rhinelander Mill that historically have had major sources of SO_2 emissions.[5] These facilities are PCA Tomahawk (located approximately 32.8 km away) and Red Arrow (located approximately 4.1 km away). Another small SO_2 source (stack S08) at the Rhinelander Mill that is still operating was also included in the modeling. These sources are listed in Table 4-2. Figure 4-5 shows the locations of PCA Tomahawk and Red Arrow in relation to the Rhinelander Mill.

Table 4-1: Background Sources Modeled

Stack ID	1-hr SO2 Emission Rate (g/s)	Stack Height (m)	Stack Temperature (K)	Stack Velocity (m/s)	Stack Diameter (m)
Other Rhinelander Sources					
S08	1.919	35.66	439.0	20.08	1.68
PCA Tomahawk Sources					
S14	17.680	46.60	470.4	4.64	1.37
S15A	146.900	60.70	468.0	16.50	3.23
Red Arrow Sources					
S07B	0.407	12.56	444.3	14.40	1.01
S10B	0.407	15.54	366.5	13.20	1.07

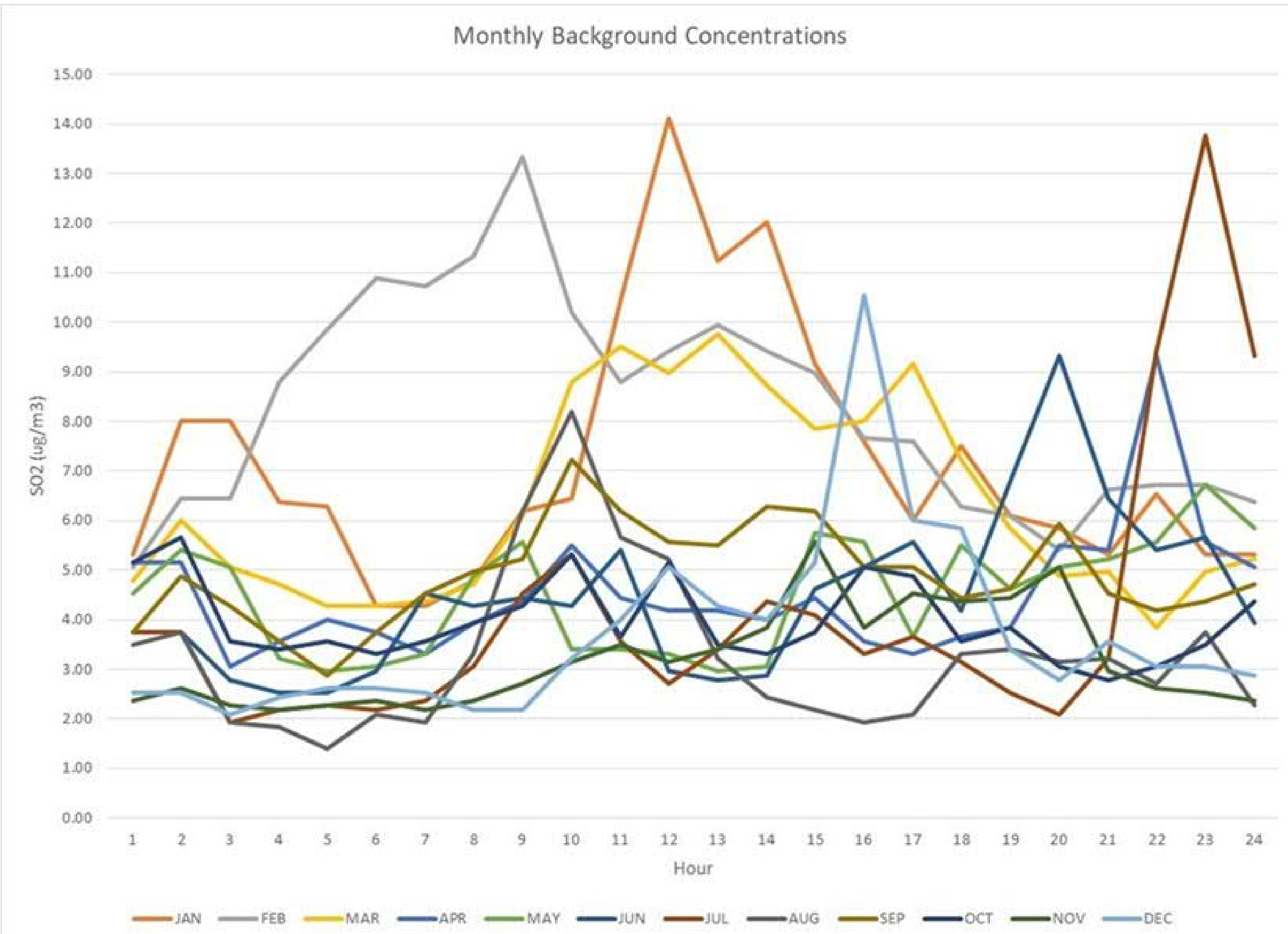
[5] PCA Tomahawk has taken restrictions on certain emission sources since the 2014 modeling was performed. Historic (higher) emission rates were conservatively utilized for this analysis.

Figure 4-5: Locations of Background Sources



Regional background concentrations are used in modeling to represent emission sources that are not directly modeled, as well as naturally occurring levels of the pollutant of interest. Once regional background levels have been identified, they are added to the modeled results at each receptor for a cumulative modeling result. The monthly/hour-of-day background values used in this modeling were obtained from WDNR. Based on the WDNR's "Guidance on Air Quality Background Concentrations" document, the regional low SO_2 values derived from the 2013-2015 Horicon monitor in Dodge County, Wisconsin were used for this modeling. The values are presented in Figure 4-6.

Figure 4-6: Monthly Background Concentrations Used in Modeling



5. Worst-Case Load Determination

Appendix B documents stack test results for three ranges of heat input rate for Stack S09: 212-239 MMBtu/hr, 264-265 MMBtu/hr, and 294-300 MMBtu/hr. For these three groups, median values for the heat input rate, stack gas exit velocity, and stack gas temperature from the available stack tests were computed for use in worst-case load testing. A reference SO_2 emission rate of 2 lb/MMBtu was used to compute the lb/hr emission rates used for each load case in the modeling. Table 5-1 provides the resulting stack exhaust parameters and emission rates used in the worst-case load testing for the low, medium, and high loads.

Table 5-1: Stack Exhaust Parameters and Emission Rates Used for Worst-Case Load Tests

Heat Input Rate (MMBtu/hr)	Exit Velocity (m/s)	Exit Temperature (K)	SO_2 Emissions (g/s)	Maximum Modeled 99th Percentile Concentration (µg/m^3)
218.50	11.39	428.55	55.06	131.87
264.00	11.43	429.40	66.53	156.74
299.00	12.80	434.70	75.35	166.76

The modeling was conducted as described in Section 4, with each hour's emission rate adjusted to account for the wind tunnel-derived building downwash effects. The results of the worst-case load testing (the 5-year modeled design concentration) are provided in the rightmost column in Table 5-1 and indicate that the most constraining load case is the high load case. The associated stack exhaust parameters were used for the NAAQS-compliant modeling documented in Section 6.

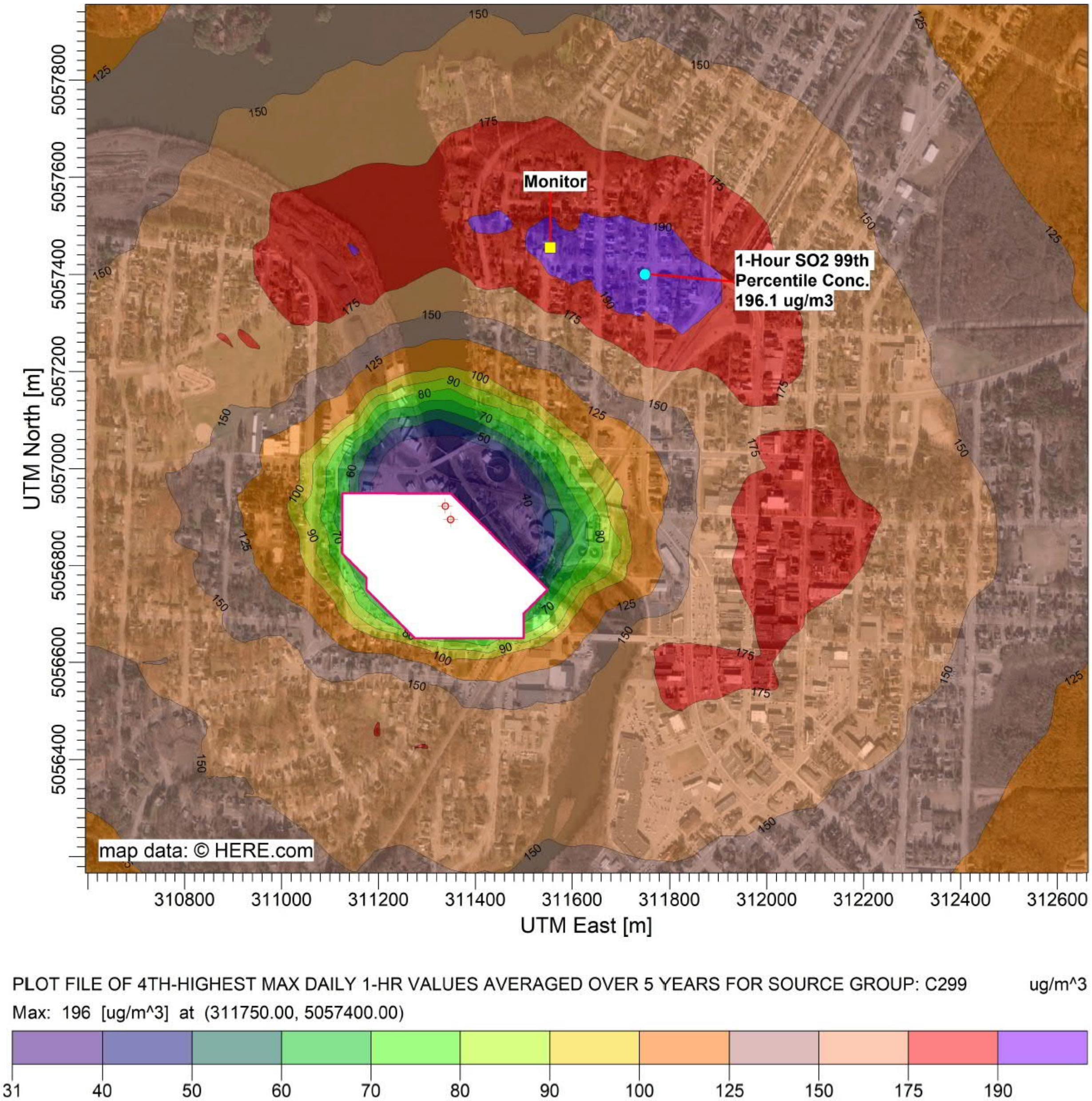
6. Modeling Results for NAAQS-Compliant SO_2 Emission Rate

SO_2 modeling was conducted for the high load case documented in Section 5 to determine a 1-hour average lb/hr NAAQS-compliant emission rate, using the modeling approach documented in Section 4. The result of this modeling analysis indicates that the complying 1-hour SO_2 emission rate is 710 lb/hr[6]. Figure 6-1 provides a concentration isopleth map of the 5-year averaged 99th percentile peak daily maximum modeled concentrations. The location of the peak modeled concentration is at about the same distance from the S09 stack as the Water Tower monitor, and the predicted concentration at the monitor is within 2% of the peak modeled concentration. Therefore, the Water Tower monitor is well sited to continue to demonstrate attainment of the SO_2 NAAQS in Rhinelander.

To determine an equivalent 24-hour SO_2 emission limit for Stack S09, the data in Appendix D of the U.S. EPA's SO_2 Nonattainment Guidance[7] (April 23, 2014) can be used in lieu of site-specific continuous emission monitoring data, which is too limited for the high load case for use in estimating the required ratio of the 99th percentile daily vs. hourly emission rates. Table 1 in that appendix specifies a 0.93 ratio for "sources with no advanced control" for the 24-hour to 1-hour emission limit, which is applicable to this source. When this factor is applied to the 1-hour emission rate, the resulting 24-hour lb/hr SO_2 emission rate is 660 lb/hr. Due to the conservative nature of the formula GEP height used, the modeled result is expected to overstate the air quality impact.

[6] Modeling with an emission rate of 709.4 lb/hr yields a peak modeled concentration of 196.1 µg/m^3, so rounding this emission rate to 710 lb/hr would still result in a peak prediction less than the NAAQS of 196.4 µg/m^3.
[7] 2. U.S. EPA, 2014. Guidance for 1-Hour SO_2 Nonattainment Area SIP Submissions. April 23, 2014. https://www.epa.gov/sites/production/files/2016-06/documents/20140423guidance_nonattainment_sip.pdf.

Figure 6-1: Concentration Isopleth Map for 5-Year Average of 99th Percentile SO_2 Concentrations



Appendix A Analysis of Wind Tunnel Modeling Results for Adjustments Needed for Building Corner Vortex Effects

Concentration Ratio Equation Development

By

Ronald L. Petersen, PhD, CCM

October 2020

In order to adjust AERMOD to account for building downwash effects, the results in Table 5 from Petersen and Beyer-Lout (2014)[8] were used. The table provides the concentration ratio, R, of maximum concentration with the buildings present to that without the buildings present for various stack heights, operating scenarios and wind speeds. The maximum and minimum operating load scenarios were found to provide very similar R values at the 85 m stack height and maximum load scenario was selected as the critical scenario for initially documenting a 90 m GEP stack height. At the 85 m stack height, R versus wind speed was documented and illustrated that R will tend to decrease as wind speed decreases. At some low wind speed (high plume rise), R will approach 1.0 as the plume will rise well beyond any building downwash effects.

To correct the AERMOD results for building downwash, a relation between *R* and the 7.93 m airport wind speed for the creditable S09 stack height is needed. Since only one wind speed (7.56 m/s) was evaluated for 87.5, 90, and 95 m stack heights while three speeds were evaluated for an 85 m height, the 85 m stack height test results shown in Table 1[9] (taken from Table 5 in Petersen and Beyer-Lout, 2014) were used to develop an equation. The equation should have the following characteristics: 1) approach 1.0 asymptotically as wind speed decreases; and 2) approach a constant value at a high wind speed where plume rise remains relatively constant. The following Gaussian type equation meets these requirements:

$$R = A\, exp\left[-\frac{\left(\frac{1}{U_{airport}}-\frac{1}{U_{max}}\right)^2}{B^2}\right] + 1.0 \qquad \text{Equation (1)}$$

where $U_{airport}$ is the Rhinelander airport wind speed at 7.9 m, U_{max} will be taken to be the 1% wind speed of 10.8 m/s and A and B are best-fit constants. Equation 1 has the following characteristics:

- as $U_{airport}$ approaches 0, *R* approaches 1,
- when $U_{airport} = U_{max}$, $R = A+1$, the maximum value, and
- when $U_{airport} > U_{max}$, *R* will tend to decrease, so *R* should be set to *A+1*, the maximum value.

Using the 85 m stack height test results in Table 1, the following best-fit constants to Equation 1 were found:

A= 0.674, and

B= 0.174

To determine *R* versus wind speed for a 90 m stack, the same equation is used except, *A* is adjusted by the ratio of the 85 and 90 m stack height observed *R* values at the 7.56 m/s wind speed in Table A-1, or

[8] Petersen, R.L. and A. Beyer-Lout. Fluid Modeling Good Engineering Practice Stack Height Determination for the Rhinelander Mill Stack S09, CPP Report 7835, October 2014.

[9] In Table 5 of Petersen and Beyer-Lout (2014), the airport wind speed height was assumed to be 10 m . Subsequent to conducting the study, it was determined that the actual anemometer height is 7.93 m (26 ft). The equivalent wind speed at 7.93 m was determined using, $U(7.9m) = U(10m)\ (7.93/10)^{0.19}$, and the resulting values are provided in Table 1.

$$\frac{(R-1)_{90}}{(R-1)_{85}} = \frac{A_{90}}{A_{85}} at\ same\ airport\ speed \qquad \text{Equation (2)}$$

After rearranging and substituting,

$$A_{90} = 0.674 \left(\frac{1.46-1}{1.63-1}\right) = 0.492 \qquad \text{Equation (3)}$$

for the 90 m stack height. The B constant remains the same.

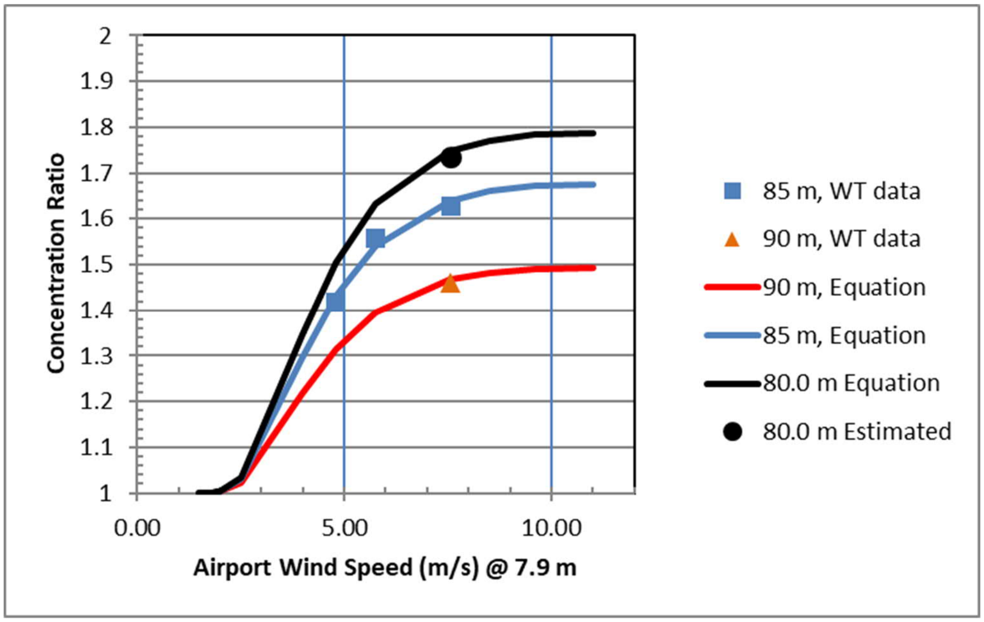
Figure A-1 below shows the observed and computed R values using Equation 1 with the A and B best-fit constants discussed above.

Table A-1: Observed and Predicted Concentration Ratios Versus Wind Speed and Stack Height

Hs (m)		$U_{airport}$ (10 m)	$U_{airport}$ (7.9 m)	Observed/ Extrapolated Ratio	Computed Ratio
80.0	m, Equation	11.49	11.00		1.79
80.0	m, Equation	10.00	9.57		1.78
80.0	m, Equation	8.88	8.50		1.77
80.0	m Extrapolated	7.90	7.56	1.736	1.747
80.0	m, Equation	6.00	5.74		1.63
80.0	m, Equation	5.00	4.78		1.50
80.0	m, Equation	4.18	4.00		1.35
80.0	m, Equation	2.61	2.50		1.03
80.0	m, Equation	2.09	2.00		1.00
80.0	m, Equation	1.99	1.90		1.00
80.0	m, Equation	1.88	1.80		1.00
80.0	m, Equation	1.57	1.50		1.00
	85 m, Equation	11.49	11.00		1.67
	85 m, Equation	10.00	9.57		1.67
	85 m, Equation	8.88	8.50		1.66
	85 m, WT data	7.90	7.56	1.63	1.64
	85 m, WT data	6.00	5.74	1.56	1.54
	85 m, WT data	5.00	4.78	1.42	1.43
	85 m, Equation	4.18	4.00		1.30
	85 m, Equation	2.61	2.50		1.03
	85 m, Equation	2.09	2.00		1.00
	85 m, Equation	1.99	1.90		1.00
	85 m, Equation	1.88	1.80		1.00
	85 m, Equation	1.57	1.50		1.00
	87.5 m, Equation	7.90	7.56	1.53	
	90 m, Equation	11.49	11.00		1.49
	90 m, Equation	10.00	9.57		1.49
	90 m, Equation	8.88	8.50		1.48
	90 m, WT data	7.90	7.56	1.46	1.47
	90 m, Equation	6.00	5.74		1.40
	90 m, Equation	5.00	4.78		1.31
	90 m, Equation	4.18	4.00		1.22
	90 m, Equation	2.61	2.50		1.02
	90 m, Equation	2.09	2.00		1.00
	90 m, Equation	1.99	1.90		1.00
	90 m, Equation	1.88	1.80		1.00
	90 m, Equation	1.57	1.50		1.00
		Wind tunnel data from Petersen and Beyer-Lout (2014)[2]			

For an 75 m GEP stack height, first the R value needs to be estimated based on observed R values at four different stack heights for the 7.56 m/s wind speed at 7.9 m as shown in Table A-2.

Figure A-1: Predicted and observed concentration ratio versus wind speed (m/s)



Next, a best fit equation was developed based upon the data in **Table A-2** as shown in **Figure A-2**. The best fit equation was then used to estimate the R value at the 75 m stack height. **Table A-2** shows that the R value for a 75 m stack is 1.772 for a reference wind speed of 7.56 m/s. The "A" value was then computed as follows:

$$A_{80} = 0.674 \left(\frac{1.736 - 1}{1.630 - 1}\right) = 0.825$$

Figure A-1 shows the estimated and computed R values using Equation 1 with the A and B best-fit constants discussed above for a 75 m stack height.

Figure A-2: Concentration ratio versus stack height and best fit equation

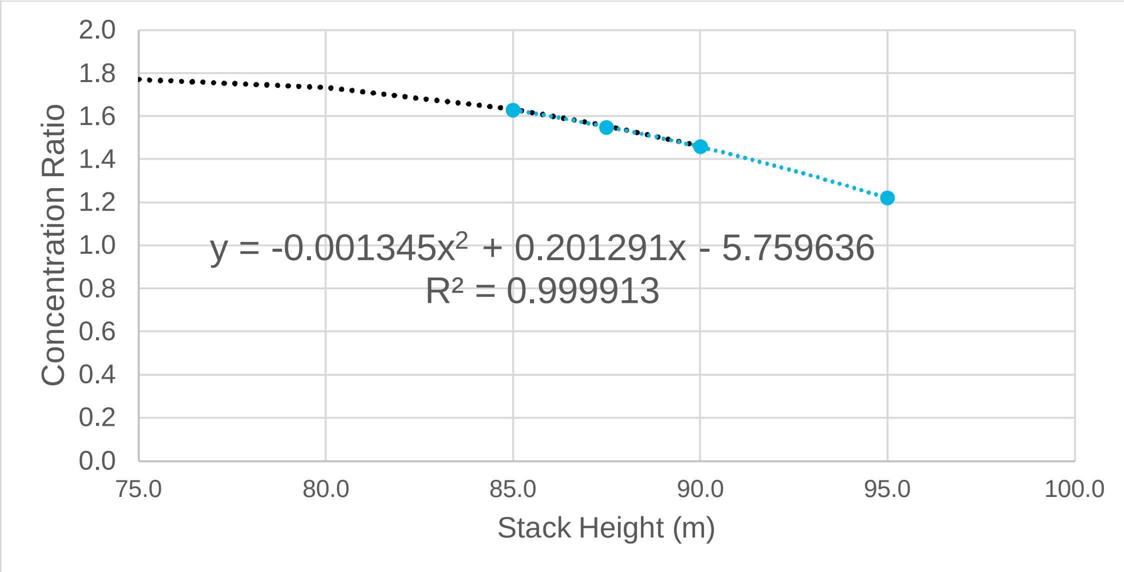


Table A-2: Predicted and observed concentration ratio versus stack height.

	Concentration Ratio	
Stack Height (m)	Observed	Predicted
75.0	NA	1.772
80.0	NA	1.736
85.0	1.630	1.632
87.5	1.550	1.556
90.0	1.460	1.462
95.0	1.220	1.224

Appendix B Excerpts of Relevant Stack Tests for Stack S09

Table B-1: Table of Stack Test Results for Stack S09

Date	Run	Velocity (m/s)	Temperature (deg. K.)	Input (MMBtu/hr)
2016[10]	1A	12.52	439.8	299
	1B	12.99	438.3	299
	2A	13.01	438.6	300
	2B	13.13	439.8	300
	3	12.09	434.6	299
	4	13.24	431.9	299
	5	12.87	435.3	299
	6	13.43	433.3	299
	7	13.08	434.9	300
	8	13.14	433.2	300
	9	13.32	434.6	300
	10	13.17	434.7	299
	11	13.09	435.5	299
	12	13.07	434.7	299
	13	12.70	434.6	296
	14	12.12	432.3	297
	15	12.89	432.2	297
	16	12.09	433.4	297
	17	12.73	433.3	298
	18	11.88	433.5	298
2017[11]	1	11.74	435.0	294
	2	12.24	435.1	294
	3	12.07	435.0	294
	4	11.33	433.5	294
	5	11.47	435.4	294
	6	11.49	435.0	294
	4A	11.43	429.2	265
	5A	11.33	429.4	264
	6A	11.48	430.5	264

[10] Report on FPM and Hg Compliance and O_2, SO_2, CO, HCl and PM CEMs Certification Test Program
CleanAir Project No: 13132-1
Revision 0: February 3, 2017
[11] Report on a 40 CFR 63 Subpart DDDDD Test Program
CleanAir Project No: 13387-1
Revision 0: December 1, 2017

2018[12] Three runs were conducted, but excluded from this analysis as outliers.

Date	Run	Velocity (m/s)	Temperature (deg. K.)	Input (MMBtu/hr)
2019[13]	1	12.14	429.3	219
	2	12.13	432.2	222
	3	12.21	433.6	223
	4	12.41	434.4	239
	5	11.45	429.1	224
	6	11.40	428.9	220
	7	11.07	426.1	213
	8	11.21	425.6	212
	9	11.21	426.2	214
	10	11.30	426.7	213
	11	11.20	424.4	218
	12	11.38	428.2	217

[12] Report on a 40 CFR 63 Subpart DDDDD Test Program
CleanAir Project No: 13688-1
Revision 0: November 28, 2018

[13] Report on a 40 CFR 63 Subpart DDDDD Test Program
CleanAir Project No: 13968
Revision 0: December 12, 2019